

Influence of body composition on bone mass in children and adolescents

WELLINGTON ROBERTO GOMES DE CARVALHO¹, EZEQUIEL MOREIRA GONÇALVES², ROBERTO REGIS RIBEIRO³, EDSON SANTOS FARIAS⁴, SARA SILVEIRA PENIDO DE CARVALHO⁵, GIL GUERRA-JÚNIOR⁶

¹ PhD in Child and Adolescent Health; Professor, Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais (IFSULDEMINAS), Centro de Ciências Aplicadas à Educação e Saúde (CeCAES), Campus Muzambinho, Muzambinho, MG, Brazil

² MSc in Child and Adolescent Health; PhD Student, Postgraduate Program in Child and Adolescent Health, Faculdade de Ciências Médicas, Universidade Estadual de Campinas (FCM-UNICAMP), Campinas, SP, Brazil

³ PhD in Child and Adolescent Health; Professor, Department of Physical Education, Faculdade Assis Gurgacz, Cascavel, PR, Brazil

⁴ PhD in Child and Adolescent Health; Professor, Centro de Ciências da Saúde e do Desporto (CCSD), Universidade Federal do Acre (UFAC), Rio Branco, AC, Brazil

⁵ Physical Education Professional; Universidade Vale do Rio Verde (UNINCOR), Três Corações, MG, Brazil

⁶ Associate Professor of the Department of Pediatrics, FCM-UNICAMP, Campinas, SP, Brazil

SUMMARY

Objective: To evaluate the influence of body composition on bone mass in children and adolescents. **Methods:** A cross-sectional study with 267 healthy students of both sexes (141 males and 126 females) aged 8 to 18 years. Weight, height, body mass index, lean mass, fat mass, fat mass index, body fat percentage, waist and hip circumferences, and waist-to-hip ratio were evaluated. Bone mass was assessed using ultrasound of hand phalanges (DBM Sonic BP – IGEA, Carpi, Italy). **Results:** Females showed greater bone mass in relation to males with advances in age and pubertal stage. In both sexes, the bone mass showed significant and positive correlations with age, weight, height, body mass index, lean mass, waist and hip circumferences; and negative correlations with waist-to-hip ratio. In females, there was also a positive correlation with fat mass, fat mass index, and body fat percentage. Age and lean mass were predictors for bone mass in males, and age, pubertal stage and fat mass index were predictors in females. **Conclusion:** The correlation between bone mass and body composition occurred in both sexes, with lean mass and fat mass index being the predictor of bone mass in males and females, respectively.

Keywords: Ultrasonography; bone density; finger phalanges; obesity; school health.

Study conducted at the Laboratory of Growth and Body Composition, Centro de Investigação em Pediatria (CIPEd), Department of Pediatrics, Faculdade de Ciências Médicas, Universidade Estadual de Campinas (FCM-UNICAMP), Campinas, São Paulo, SP, Brazil

Submitted on: 04/27/2011
Approved on: 09/06/2011

Financial Support:
Capes (Doctoral grants to WRGC and EMG)

Correspondence to:
Gil Guerra-Júnior
Cidade Universitária
"Zeferino Vaz"
CEP: 13083-970
Campinas, SP, Brazil
Phone: +55 (19) 3521-7322
gilguer@fcm.unicamp.br

Conflict of interest: None.

©2011 Elsevier Editora Ltda.
All rights reserved.

INTRODUCTION

The assessment of body composition in children and adolescents is of great importance, as it expresses the life and health status of the population and its influence on the morbimortality risks. The incidence of obesity has been increasing steadily around the world and can be currently considered a major public health problem¹. Childhood has been identified as a critical period for the development of obesity^{2,3}.

In contrast to such consequences, studies have suggested that obesity seems to be a protective factor against risk of fractures and osteoporosis⁴, given that obese individuals have greater bone mass compared with normal weight individuals⁵. In theory, the greater bone mass in obese individuals may be a consequence of increased body weight.

The actual contribution of fat mass to bone mass remains controversial. Arabi et al.⁶ carried out a cross-sectional study conducted with 363 school children aged 10 to 17 years and observed that the lean and fat masses were predictors of bone mass in boys and girls.

It was observed that bone mass assessment in children and adolescents is important not only for the development of intervention programs, but mainly because the accumulation of bone mass during the growth phase plays an important factor in preventing osteoporosis in the adult phase⁷. Studies leading to a better understanding of this question are of great interest for the scientific community, especially considering that the contribution of body composition to bone mass is not yet fully understood.

Hence, the purpose of this study was to evaluate the influence of body composition on bone mass in children and adolescents.

METHODS

This is cross-sectional study carried out with school children of both sexes, aged 8 to 18 years, enrolled in a public school in the city of Francisco Morato, located in the north-northeast region of the state of São Paulo, Brazil. The study was approved by the Ethics Committee of Faculdade de Ciências Médicas of Universidade Estadual de Campinas (protocol # 504/2009) and informed written consent was given by the school direction and by the students' parents and/or tutors.

All students enrolled in the school in the year 2009 were included. Exclusion criteria were the presence of physical disability (permanent or temporary) that would prevent assessments, use of drugs that could interfere with body composition or bone mass, non-compliance by parents or students, or non-attendance at the evaluation. The sample consisted of 267 students (males = 141 or 52.8% and females = 126 or 47.2%).

The chronological ages were established by calculating decimal age, having as reference the date of birth and of data collection, adopting decimal intervals between 0.50 to 0.49

according to Eveleth and Tanner⁸, i.e., for a child to be included in the age group of eight years, he or she would have to be a centesimal age of 7.50 to 8.49 years at the time of data collection. Based on this data, all students were divided into groups of 8 to 10 years, 11 to 13 years, 14 to 16 years and 17 to 18 years.

The economic profile was verified according to criteria suggested by the Brazilian Association of Research Companies⁹, and all students belonged to socioeconomic classes C (28.5%), D (58.8%) or E (12.7%).

All measurements were performed according to standard techniques¹⁰. Weight was measured (in kilograms) using a portable digital scale with a 0.1 kg precision. Height was measured (in centimeters) using a vertical stadiometer with a 0.1 cm precision. Based on these measurements, body mass index (BMI) was obtained by dividing weight (in kilograms) by height (in meters) squared.

The skinfold thickness in the tricipital (TRI) and subscapularis (SBS) regions were measured on the right side of the body, by a single previously trained experienced examiner, using an adipometer (Holtain Tanner-Whitehouse Skinfold Caliper, UK) with a 0.2 mm precision. Based on the sum of skinfold thickness of the TRI and SBS regions, we used the equations of Slaughter et al.¹¹ to calculate the percentage of body fat (%BF). Based on these data, the fat mass (FM) was obtained by multiplying the %BF content by weight and the fat mass index (FMI) was obtained by dividing the FM by the height squared. The lean mass (LM) was obtained by subtracting the weight by the fat mass.

Waist circumference (WC) was measured using a metallic measuring tape with a precision of 0.1 cm, by measuring around the waist at the narrowest part of the trunk, between the last rib and the iliac crest, with the subjects in the standing position after a normal expiration. Hip circumference (HC) was measured with subjects in the standing position, using a metallic measuring tape with a precision of 0.1 cm, by measuring around the maximum posterior extension of the buttocks. The waist-to-hip ratio (WHR) was then calculated using these measures, by dividing the WC by HC.

Bone mass (Amplitude Dependent Speed of Sound, AD-SoS) was evaluated using the third generation of the DBM Sonic BP device (IGEA, Carpi, Italy). The technique is based on transmission of ultrasound signals using a compass that attaches two transducers, one acting as transmitter and another as receiver of ultrasound, 12 mm in diameter, with a precision of ± 0.02 mm. The compass was placed on the distal metaphysis of each of the last four proximal phalanges (II-V) in the non-dominant hand of the patient, of which acoustic coupling was performed using standard ultrasound gel. The transducer emits a sound wave of 1.25 MHz that runs through the elements that constitute bone tissue, while the other transducer receives the signal and evaluates the speed of sound propagation through the phalanx.

The AD-SoS is obtained automatically and represents 96 acquisitions of ultrasound velocity measurements (m/s), ranging from 1650 to 2250 m/s. The AD-SoS assesses the speed of ultrasound (m/s), which, by transmission, scans the trabeculae of bone tissue in the four proximal phalanges¹².

The stage of sexual maturation was evaluated by self-assessment¹³, with the help of boards with specific pictures for each sex according to the stage of breast development (M1-5) for girls¹⁴ and genitals (G1-5) for boys¹⁵, classified as prepubertal (stage I), intrapubertal (stages II and III) and pubertal (stages IV and V). Menarche was assessed by asking the girls whether it had occurred and when. All the girls that had had menarche were included in the pubertal group (stage IV or V).

Data storage and statistical analysis were performed using the SPSS (Statistical Package for Social Sciences, Inc., Chicago, IL, USA) software, release 16.0. The data were processed using descriptive procedures, and mean, median, standard deviation, minimum and maximum values were calculated. Data distribution was verified regarding normality using the Kolmogorov-Smirnov test. For variables with normal distribution, data were presented as mean and standard deviation, and for variables with non-normal distribution, as median, minimum and maximum values. The Mann-Whitney test was used to compare differences between the sexes. Spearman's correlation test was used to verify the correlations between bone measurement data and anthropometric variables and body composition. Step-by-step multivariate linear regression analysis was used to determine the possible effects of each independent variable (age, weight, height, BMI, LM, FM, FMI, %BF, WC, HC, WHR and pubertal stage) on the dependent one (AD-SoS). The results were considered statistically significant at $p < 0.05$.

RESULTS

The results of body composition by age, sex and pubertal stage are shown in Table 1 and the bone mass results (in AD-SoS) in Table 2.

It was observed that 57 (45.2%) girls had had menarche, with age ranging from 9.9 to 14.6 years (12.2 ± 1.1 years).

Spearman's linear correlation coefficients demonstrated that in both sexes, AD-SoS showed significant positive correlations with age, weight, height, BMI, LM, WC, HC and a significant negative correlation with WHR. Only in girls, the AD-SoS showed significant positive correlations with FM, FMI and %BF (Table 3).

The step-by-step multivariate linear regression analysis showed that the most important variables as independent predictors of AD-SoS were age and lean mass, with a coefficient of determination (R^2) of 0.348 in boys and age, pubertal stage and FMI with a coefficient of determination (R^2) of 0.588 in girls (Table 3).

DISCUSSION

The present study observed, with age increase, higher values of weight, height, LM, WC and WHR for boys in relation to girls and FM, FMI, %BF and HC for girls in relation to boys. In general, these were consistent with other studies and these gender differences can be explained by sexual dimorphism. The differences between the sexes occur in response to genetic determinants, hormonal and environmental influences, acting since the prenatal period and showing variability in their progression at the time of puberty¹⁶.

Gültekin et al.¹⁷, in a cross-sectional study that evaluated 332 boys and 269 girls from Turkey aged 8 to 11 years, showed clear evidence of sexual dimorphism in the body fat pattern; girls showed greater body fat content. In the present study, the anthropometric and body composition variables followed an expected result according to pubertal stage progression. Higher LM value in boys was observed in the pre-pubertal group, when compared with girls. A higher WHR was observed in boys in the intrapubertal group when compared to girls, but the latter had higher values of FM, FMI, %BF and HC in relation to boys.

Boys in the pubertal group had higher height and LM values when compared to girls, but the latter had higher BMI, FM, FMI, %BF and HC values in relation to boys.

These results can be explained by the natural process of pubertal development, as the growth spurt occurs during puberty, as well as changes in body composition. During the growth and development of children, the content, proportion and distribution of body fat may change with age, especially in the pre- and post-adolescence phase, when girls continue to present an increase in fat mass¹⁸.

In the present study, the bone mass showed the expected increase for age and pubertal stage. It was observed that girls in general and those at the intrapubertal and pubertal stages had greater bone mass than boys, corroborating data from cross-sectional^{19,20} and longitudinal studies²¹⁻²³.

Adolescence is a critical period for bone mineralization and bone mass acquisition during the pubertal phase has a strong association with Tanner stages²⁴. Studies have shown that bone mass is greater in girls when compared with boys until late adolescence²⁵, but these differences may disappear with growth velocity and pubertal development²⁶. In this study, the differences between boys and girls persisted both in the intrapubertal and pubertal groups.

Rocher et al.²⁷ in a cross-sectional study that evaluated 20 obese children and 23 controls of both sexes aged 9 to 12 years, demonstrated that bone mass in prepubertal children was not affected by obesity. Based on these findings the authors suggest that perhaps obesity does not exert a protective effect on bones.

Table 1 – Mean (M), median (Md) and standard deviation (SD) values, age (years), anthropometric variables and body composition, regarding sex and pubertal stage, Francisco Morato (SP), Brazil, 2009

Variables	Male (n = 141)				Female (n = 126)			
	Age				Age			
	8-10 (n = 44)	11-13 (n = 58)	14-16 (n = 32)	17-18 (n = 7)	8-10 (n = 36)	11-13 (n = 49)	14-16 (n = 32)	17-18 (n = 9)
Weight (kg)	31.7 ± 7.3	42.3 ± 10.4	57.1 ± 13.3	66.8 ± 14.9*	32.0 ± 7.0	43.7 ± 9.3	55.0 ± 10.2	55.3 ± 4.7
Height (cm)	133.0 ± 6.7	149.3 ± 9.2	166.7 ± 10.2*	169.2 ± 3.6*	134.0 ± 6.5	148.9 ± 8.2	159.2 ± 6.0	159.6 ± 3.8
BMI (kg/m ²)	16.6 (14.4-27.4)	18.3 (14.4-28.6)	19.4 (15.8-28.4)	20.8 (20.4-32.9)	17.0 (13-24.2)	19.1 (14.8-25.5)	21.4 (15.2-30.3)	22.0 (18.0-25.9)
FM (kg)	3.4 (1.5-19.6)	4.4 (1.6-27.1)	5.2 (1.8-29.6)	11.4 (4.7-45.0)	5.3* (2.1-17.0)	8.3* (3.5-20.6)	12.4* (1.1-32.0)	12.7 (9.8-22.3)
LM (kg)	26.8 ± 3.8	35.9 ± 7.1	50.0 ± 9.4*	53.7 ± 4.1*	25.9 ± 4.3	34.2 ± 5.4	41.3 ± 5.5	41.8 ± 2.1
FMI (kg/m ²)	1.9 (1.0-1.9)	2.0 (0.9-11.4)	1.8 (0.7-9.6)	2.4 (1.7-15.2)	3.0* (1.3-7.8)	3.6* (1.8-8.2)	4.8* (0.4-12.4)	5.2* (3.6-9.4)
% BF	11.3 (6.0-36.0)	11.9 (5.9-39.5)	9.3 (4.2-33.9)	11.4 (8.6-46.1)	18.0* (9.3-32.4)	18.9* (12.2-33.7)	22.8* (15.0-40.9)	24.1* (5.0-19.9)
WC (cm)	57.9 ± 5.9	62.2 ± 6.5	68.3 ± 9.0	73.5 ± 9.5*	57.3 ± 6.6	60.9 ± 5.4	65.7 ± 6.0	65.2 ± 3.7
HC (cm)	68.7 ± 8.2	75.5 ± 8.6	83.7 ± 7.7	92.1 ± 11.5	70.8 ± 7.3	80.0 ± 9.0*	89.7 ± 7.5*	91.0 ± 4.3
WHR (cm)	0.85 ± 0.04*	0.83 ± 0.04*	0.80 ± 0.03*	0.80 ± 0.02*	0.81 ± 0.04	0.76 ± 0.04	0.73 ± 0.03	0.72 ± 0.02

Variables	Male (n = 141)			Female (n = 126)		
	Age			Age		
	Prepubertal 9.1 ± 1.1 (n = 9)	Intrapubertal 10.4 ± 1.5 (n = 64)	Pubertal 14.0 ± 1.8 (n = 68)	Prepubertal 9.3 ± 1.5 (n = 9)	Intrapubertal 10.4 ± 1.4 (n = 64)	Pubertal 14.4 ± 1.8 (n = 68)
Weight (kg)	30.8 ± 5.1	34.0 ± 7.9	54.6 ± 13.4	27.2 ± 3.7	35.8 ± 8.1	53.4 ± 9.0
Height (cm)	132.3 ± 5.9	137.8 ± 8.3	162.4 ± 10.6*	129.4 ± 1.3	139.9 ± 9.6	157.1 ± 6.2
BMI (kg/m ²)	17.4 (13.9-26.1)	16.6 (13.9-27.5)	19.3 (16.6-28.3)	15.5 (13.4-21.1)	17.2 (13.3-23.7)	21.3* (14.7-28.7)
FM (kg)	4.2 (1.4-17.3)	3.5 (1.3-30.1)	5.2 (3.0-37.9)	4.3 (2.0-9.3)	5.7* (1.9-17.9)	12.5* (4.9-26.5)
LM (kg)	26.0 ± 3.0*	28.9 ± 4.7	46.4 ± 9.2*	22.4 ± 1.3	28.8 ± 5.3	40.2 ± 4.9
FMI (kg/m ²)	2.3 (1.4-4.9)	1.8 (0.9-9.9)	2.0 (0.7-15.2)	2.5 (1.5-4.9)	3.0* (1.3-8.1)	5.0* (0.4-12.4)
%BF	12.9 (6.7-35.8)	11.2 (5.6-49.1)	10.3 (6.7-47.5)	16.2 (9.5-29.7)	17.5* (9.5-39.2)	23.4* (13.9-38.1)
WC (cm)	57.5 ± 4.0	58.5 ± 5.9	67.6 ± 8.2	55.0 ± 4.5	58.2 ± 6.0	65.1 ± 5.6
HC (cm)	67.3 ± 7.4	69.8 ± 7.7	83.2 ± 8.8	65.3 ± 5.2	73.5 ± 7.9*	88.6 ± 7.1*
WHR (cm)	0.86 ± 0.05	0.84 ± 0.04*	0.81 ± 0.03*	0.84 ± 0.03	0.79 ± 0.05	0.74 ± 0.03

BMI, body mass index; FM, fat mass; LM, lean mass; FMI, fat mass index; %BF, percentage of body fat; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; *p < 0.05; Mann-Whitney non-parametric test.

Our findings demonstrated that in both sexes, AD-SoS showed significant positive correlations with age, weight, height, BMI, LM, WC, HC and a significant negative correlation with WHR, but only in girls the AD-SoS showed significant positive correlations with FM, FMI and %BF.

The AD-SoS was associated with the anthropometric and body composition variables. Considering that, it might be possible to confirm that the AD-SoS can provide accurate information on bone mass accumulation and microarchitectural alterations with the growth process, as suggested by some studies²⁸.

Based on the literature, it can be observed that there is inconsistency in the results of studies investigating the influence of body fat on bone mass among different populations. Wosje et al.²⁹, in order to verify the association between fat mass and bone mass gain, and the role of physical activity, assessed 214 children aged 3.5 to 7 years and demonstrated that fat mass was associated with bone mass and time spent watching TV was associated with lower gains in bone mass. Lippo et al.³⁰, in a case-control study, showed that female adolescents are at greater risk for physical inactivity, and spend more time watching TV.

Table 2 – Mean (M), median (Md), standard deviation (SD) and AD-SoS values according to age (years), pubertal stage and sex, Francisco Morato (SP), Brazil, 2009

Male (n = 141)			Female (n = 126)		
Age	n	M (Md) ± DP	Age	n	M (Md) ± DP
8-10	44	1915 (1923) ± 48	8-10	36	1935 (1937) ± 47*
11-13	58	1928 (1931) ± 45	11-13	49	1967 (1982) ± 145*
14-16	32	1991 (1987) ± 61	14-16	32	2071 (2063) ± 53*
17-18	7	2049 (2045) ± 81	17-18	9	2080 (2096) ± 38
Pubertal stage			Pubertal stage		
Prepubertal	9	1905 (1896) ± 39	Prepubertal	4	1931 (1927) ± 28
Intrapubertal	64	1921 (1930) ± 50	Intrapubertal	60	1932 (1952) ± 124*
Pubertal	68	1971 (1961) ± 67	Pubertal	62	2054 (2053) ± 60*

AD-SoS, amplitude-dependent speed of sound; *p < 0.05; Mann-Whitney non-parametric test.

Table 3 – Spearman's coefficient of linear correlation of bone quantity (AD-SoS) according to sex, anthropometric variables and body composition, and multivariate linear regression analysis of AD-SoS in relation to sex, Francisco Morato (SP), Brazil, 2009

Variables	Male (n = 141)		Female (n = 126)		
	AD-SoS		AD-SoS		
	rs	p	rs	p	
Age (years)	0.53	0.001	0.77	0.001	
Weight (kg)	0.45	0.001	0.60	0.001	
Height (cm)	0.53	0.001	0.71	0.001	
BMI (kg/m ²)	0.23	0.007	0.34	0.001	
FM (kg)	0.14	0.11	0.41	0.001	
LM (kg)	0.51	0.001	0.68	0.001	
IMG	-0.05	0.52	0.24	0.006	
%BF	-0.15	0.07	0.23	0.01	
WC (cm)	0.34	0.001	0.37	0.001	
HC (cm)	0.41	0.001	0.57	0.001	
WHR (cm)	-0.39	0.001	-0.60	0.001	
Sex	Model		R ²	R ² adjusted	p
Male	AD-SoS = 1777.048 + (9.441 x age) + (1.450 x LM)		0.357	0.348	0.0001
Female	AD-SoS = 1831.144 + (13.613 x age) + (66.514 x pubertal stage) + (-7.306 x FMI)		0.598	0.588	0.0001

BMI, body mass index; FM, fat mass; LM, lean mass; FMI, fat mass index; %BF, percentage of body fat; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio.

In view of that, physical inactivity may contribute to increased adiposity.

The present study demonstrated, in this group of students, that age and lean mass were independent predictors of AD-SoS for boys, and age, pubertal stage and FMI were independent predictors of AD-SoS for girls. This finding demonstrates that the independent variables age and lean mass can explain 34.8% of the variability in AD-SoS in boys, and that age, pubertal stage and FMI can explain 58.8% of the variability in AD-SoS in girls.

Some limiting factors can be mentioned in this study,

such as not comparing ultrasound data with other methods such as DXA, not assessing the intake of specific nutrients for the acquisition of bone mass such as calcium and vitamin D and not assessing the level of physical activity.

Although the physiological basis for explaining the association between weight, body fat distribution and bone mass remains uncertain, particularly when considering different population groups, the data from this study open perspectives to the influence of peri- and intrapubertal body composition, as we clearly observe more LM in the male sex and more FM in the female sex.

CONCLUSION

It was concluded in this study with children and adolescents that there was a correlation between bone mass and body composition, with LM being a predictor of bone mass in boys and FMI in girls.

ACKNOWLEDGEMENTS

The authors would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the doctoral grants (to WRGC and EMG), the school Principal, the students and their parents or tutors who collaborated with the study.

REFERENCES

- Orsi CM, Hale DE, Lynch JL. Pediatric obesity epidemiology. *Curr Opin Endocrinol Diabetes Obes.* 2011;18:14-22.
- Kim S, Popkin BM. Commentary: Understanding the epidemiology of overweight and obesity - a real global public health concern. *Int J Epidemiol.* 2006;35:60-7.
- Parisi SM, Goodman E. Obesity and cardiovascular disease risk in children and adolescents. *Curr Cardiovasc Risk Rep.* 2008;2:47-52.
- Ducher G, Bass SL, Naughton GA, Eser P, Telford RD, Daly RM. Overweight children have a greater proportion of fat mass relative to muscle mass in the upper limbs than in the lower limbs: implications for bone strength at the distal forearm. *Am J Clin Nutr.* 2009;90:1104-11.
- Wang MC, Bachrach LK, Van Loan M, Hudes M, Flegal KM, Crawford PB. The relative contributions of lean tissue mass and fat mass to bone density in young women. *Bone.* 2005;37:474-81.
- Arabi A, Tamim H, Nabulsi M, Maalouf J, Khalifé H, Choucair M, et al. Sex differences in the effect of body-composition variables on bone mass in healthy children and adolescents. *Am J Clin Nutr.* 2004;80:1428-35.
- Mora S, Gilsanz V. Establishment of peak bone mass. *Endocrinol Metab Clin North Am.* 2003;32:39-63.
- Eveleth PH, Tanner JM. *Worldwide variation in human growth.* Cambridge: Cambridge University Press; 1976.
- Associação Brasileira de Empresas de Pesquisa (ABEP). Critério de classificação econômica Brasil [cited 2009 Feb 20]. Available from: <http://www.abep.org>.
- Lohman TG, Roche AF, Martorell R. *Anthropometric standardization reference manual.* Champaign: Human Kinetics; 1988.
- Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, Van Loan MD, et al. Skinfold equations for estimation of body fatness in children and youth. *Hum Biol.* 1988;60:709-23.
- Halaba ZP, Pluskiewicz W. Quantitative ultrasound in the assessment of skeletal status in children and adolescents. *Ultrasound Med Biol.* 2004;30:239-43.
- Duke PM, Litt IF, Gross RT. Adolescents' self assessment of sexual maturation. *Pediatrics.* 1980;66:918-20.
- Marshall WA, Tanner JM. Variations in the pattern of pubertal changes in girls. *Arch Dis Child.* 1969;44:291-303.
- Marshall WA, Tanner JM. Variations in the pattern of pubertal changes in boys. *Arch Dis Child.* 1970;45:13-23.
- Taylor RW, Grant AM, Williams SM, Goulding A. Sex differences in regional body fat distribution from pre- to postpuberty. *Obesity.* 2010;18:1410-16.
- Gültekin T, Akin G, Ozer BK. Gender differences in fat patterning in children living in Ankara. *Anthropol Anz.* 2005;63:427-37.
- Ma J, Feng N, Zhang SW, Pan YP, Huang YB. Comparison of changes in body composition during puberty development of obese and normal-weight children in China. *Biomed Environ Sci.* 2009;22:413-8.
- Ribeiro RR, Guerra-Junior G, Barros-Filho. Bone mass in schoolchildren in Brazil: the effect of racial miscegenation, pubertal stage, and socioeconomic differences. *J Bone Miner Metab.* 2009;27:494-501.
- Kalkwarf HJ, Gilsanz V, Lappe JM, Oberfield S, Shepherd JA, Hangartner TN, et al. Tracking of bone mass and density during childhood and adolescence. *J Clin Endocrinol Metab.* 2010;95:1690-8.
- Lappe JM, Stegman MR, Davies KM, Barber S, Becker RR. A prospective study of quantitative ultrasound in children and adolescents. *J Clin Densitom.* 2000;2:167-75.
- Vignolo M, Parodi A, Mascagni A, Torrisi C, De Terlizzi F, Aicardi G. Longitudinal assessment of bone quality by quantitative ultrasonography in children and adolescents. *Ultrasound Med Biol.* 2006;32:1003-10.
- Halaba ZP. Quantitative ultrasound measurements at hand phalanges in children and adolescents: a longitudinal study. *Ultrasound Med Biol.* 2008;34:1547-53.
- Dib L, Arabi A, Maalouf J, Nabulsi M, El-Hajj Fuleihan G. Impact of anthropometric, lifestyle, and body composition variables on ultrasound measurements in school children. *Bone.* 2005;36:736-42.
- Jones G, Dwyer T. Bone mass in prepubertal children: gender differences and the role of physical activity and sunlight exposure. *J Clin Endocrinol Metab.* 1998;83:4274-9.
- Baxter-Jones AD, Mirwald RL, McKay HA, Bailey DA. A longitudinal analysis of sex differences in bone mineral accrual in healthy 8-19-year-old boys and girls. *Ann Hum Biol.* 2003;30:160-75.
- Rocher E, Chappard C, Jaffre C, Benhamou CL, Courteix D. Bone mineral density in prepubertal obese and control children: relation to body weight, lean mass, and fat mass. *J Bone Miner Metab.* 2008;26:73-8.
- Fricke O, Tutlewski B, Schwahn B, Schoenau E. Speed of sound: Relation to geometric characteristics of bone in children, adolescents, and adults. *J Pediatr.* 2005;146:764-8.
- Wosje KS, Khoury PR, Claytor RP, Copeland KA, Kalkwarf HJ, Daniels SR. Adiposity and TV viewing are related to less bone accrual in young children. *J Pediatr.* 2009;154:79-85.
- Lippo BR, da Silva IM, Aca CR, de Lira PI, da Silva GA, Motta ME. Determinants of physical inactivity among urban adolescents. *J Pediatr (Rio J).* 2010;86:520-4.